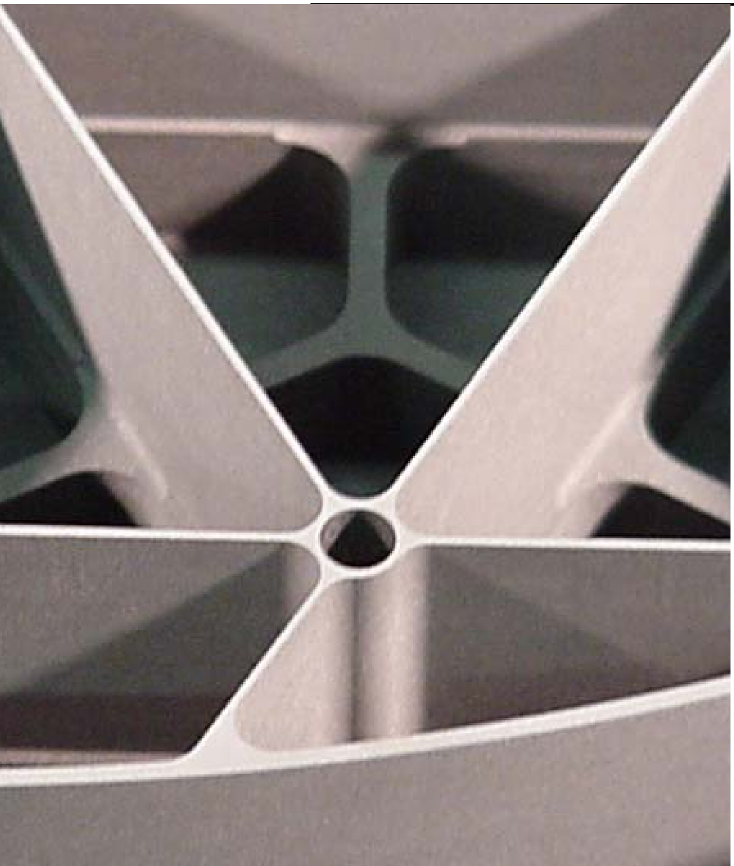
POCO Optics Project



Silicon Carbide for Space and Defense Applications

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Database Development

Data on SuperSiC®

- Poco has a 10 year legacy in manufacturing SiC for semiconductor applications
  - Precision parts
  - High purity
- A material property database has been developed on PRODUCTION material
- The current project is aimed at developing a database specifically for aerospace and optics applications – a higher standard

Engineering Property Development

- The objective of this task is to build the Engineering foundation needed to design, fabricate, test, and ultimately fly POCO produced SiC components and assemblies.
- POCO has contracted independent labs ATK-COI and UDRI
- Testing performed
    - Basic Engineering Property Testing
    - Engineering Properties of Conversion Bonded Joints
    - Engineering Properties of Bonded and non-bonded Inserts
    - Engineering Material Properties Specific to Space Flight Optical Systems
    - CVD SiC Coating Properties

Basic Engineering Property Testing

- Tested SuperSiC® in quantities to generate design allowables.
- Tested mechanical properties at ambient and cryo
- Developed both modulus and strength in tension, compression, and shear.
- Electrical and thermal conductivity quantified for ambient conditions.
- The thermal expansion behavior was quantified over a wide temperature range (-250°F to +250°F)

Engineering Properties of Conversion Bonded Joints

- POCO's CVC process allows for assembly of complex multiple graphite components and "conversion bonding" to form monolithic SiC components.
- Graphite coupons were assembled and joined through conversion-bonding into monolithic SiC components.
- The basic mechanical properties of a few fundamental joint geometries (butt-joint, T-joint,) were tested
- Results demonstrate that the bond can achieve monolithic strength

Engineering Properties of Inserts

- Metallic inserts were adhesively bonded in SiC components.
- Helical inserts were inserted into SiC threads, without adhesive
- Insert assemblies were tested for torque capacity and pull-out strength.
- Results are very promising for use of bonded and non-bonded inserts for attachments

Engineering Material Properties Specific to Space Flight Optical Systems

- Various “stability” requirements are typically included in the specifications of space flight optical systems.
- Long-duration testing of SiC coupons was conducted to determine basic properties of temporal stability, and creep.
- Residual stress in brittle materials is thought to provide a driving force for potential problems in these types of environmental conditions.
- SuperSiC® was evaluated against typical requirements for low/no outgassing and moisture affects with excellent results

CVD SiC Coating Properties

- POCO applies a CVD SiC coating to mirror substrates, to provide a non-porous surface to polish.
- Adhesion of CVD SiC to POCO substrates was evaluated and found to be excellent
- Previous studies have found that typical optical coatings have excellent adhesion to POCO's CVD SiC.

Property Table on SuperSiC®

Poco is just now completing a \$0.5 million data development effort.

Property		SuperSiC-1	SuperSiC-5	Comments
Apparent Density, ρ_a (g/cm^3)		3.13	3.01	ASTM C-373 Standard Method *(POCO Materials Testing Lab.)*
Bulk Density, ρ_b (g/cm^3)		2.53	2.93	
Total Porosity, P_t (%)		20	4	
Open Porosity, P_{op} (%)		19	0.5	
Total Impurity Level (ppm)		<10	<5	GDMS *(Shiva)*
Flexural Strength (MPa/ksi) (m is Weibull modulus)	@ RT	147/21.3 (m=17)	201/29.2 (m=13)	ASTM C-1161, 4-Point *(ORNL/HTML)*
	@ 1000°C	146/21.2 (m=16)	197/28.6	ASTM C-1211, 4-Point *(ORNL/HTML)*
	@ 1300°C	148/21.5 (m=19)	194/28.2	
Tensile Strength (MPa/ksi)		129/18.7 (m=16)	116/16.8	ASTM C-1273 *(ORNL/HTML)*
Elastic Modulus, E (GPa/msi)		218/32	354/51 (UPE)	Tensile test, extensiometer *(ORNL/HTML)*
Specific Stiffness, E/ρ_b (kN-m/g)		85	121	Calculated
Poisson's Ratio, ν		0.17		ASTM C-1259 *(Grindosonic, J.W. Lemmens)*
Dynamic Shear Modulus, G (GPa/msi)		96/14		
Fracture Toughness, K_{IC} (MPa·m$^{0.5}$)		2.30	2.63	Single edge notched beam *(CoorsTek Analytical Lab)*
Hardness (kg/mm^2)		1992	1643	Knoop, 500g load *(CoorsTek Anal. Lab)*
Thermal Diffusivity, D (10^{-6} m^2/s)		102	115	Laser flash method *(POCO MTL)*
Thermal Conductivity at RT, κ (W/m·K)		170	220	Laser flash method *(POCO MTL)*
Mean Coefficient of Thermal Expansion, α_m (10^{-6}/K)	@ 500°C	4.0(1)		ASTM E-228 (Push rod dilatometer, *POCO MTL)*
	@ 1000°C	4.4(1)		
	@ 25°C	2.4		ASTM E-289 (Interferometry, *COI)*
Thermal Distortion Coefficients	Steady, α/κ (μm/W)	0.012	0.009	Calculated
	Transient, α/D (s/m^2·K)	0.020		Calculated
Thermal Stress, $\kappa/\alpha \cdot E$ (10^6 W·m/N)		390		

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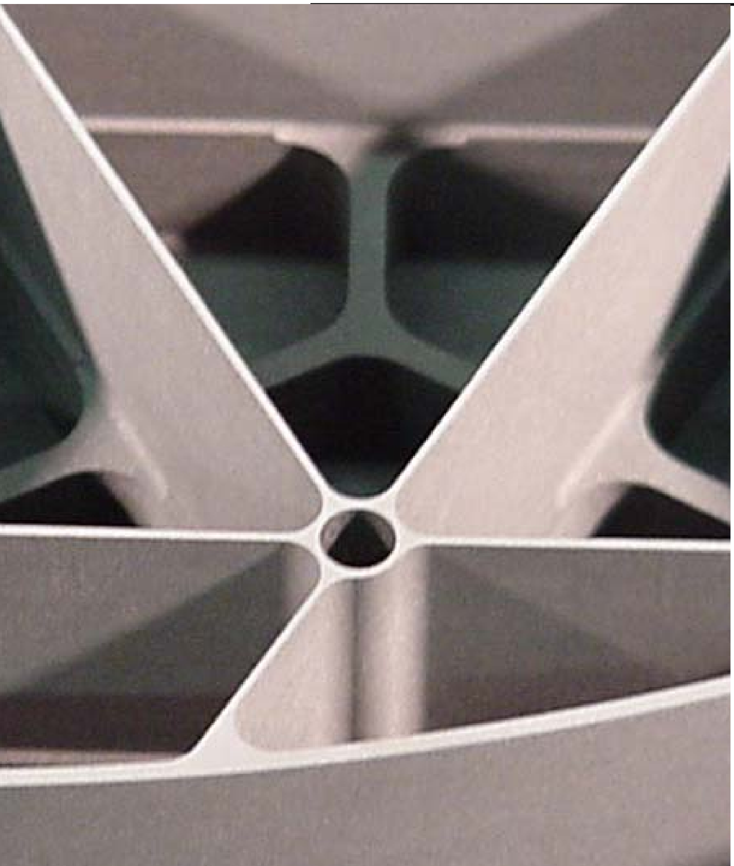

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Fracture and Fatigue Testing

Fracture Mechanics of SuperSiC

- The objective of this task is to expand the Engineering foundation needed to design, fabricate, test, and ultimately fly POCO produced SiC components and assemblies.
- POCO has contracted independent lab University of Dayton Research Institute to study fracture mechanics of SuperSiC®
- UDRI has begun fracture analysis and is scheduled to be finished by mid 2007.
- Five sets of tests are being performed
  - Biaxial Flexure Testing.
  - Dynamic Fatigue Testing.
  - Tensile Dynamic Fatigue.
  - Fracture Toughness
  - Mechanical Cyclic Fatigue
- The test plan will evaluate both Poco Graphite’s SiC-1 and SiC-5 grades of silicon carbide.

Biaxial Flexure Testing

- Measures the quality of the material surface finish and detects anisotropy effects.
- Data generates strength, Weibull modulus values and types of flaw populations.
- Testing will be conducted at room temperature and liquid nitrogen temperature.
- Sample geometry is the Equibiaxial Flexure specimen.

Dynamic Fatigue Testing

- Silicon carbide can be susceptible to slow crack growth in water vapor.
- The data from these tests will be used to calculate the fracture mechanics parameters
- The environmental constant and slow crack growth exponents will determined
- Tests will be performed at room temperature and liquid nitrogen temperature.
- The sample geometry is an Equibiaxial Flexure specimen.

Tensile Dynamic Fatigue

- Determine bulk dynamic fatigue effects using tensile test in water vapor.
- Two different stressing rates in water
- Both room temperature and at liquid nitrogen temperature
- Determine slow crack growth exponent and environmental constants
- Sample geometry is the Tensile Specimen

Fracture Toughness

- A sharp V-notched sample will be used to determine the fracture toughness
- Testing will be in water vapor
- Testing will be at room temperature and at liquid nitrogen temperature.

Mechanical Cyclic Fatigue

- Classical materials degradation by fatigue will be determined using a tension compression cycle at room temperature.
- A tension compression cycle is the most aggressive cycle and will give a conservative fatigue limit.
- In this project, the fatigue limit will be determined.
- Sample geometry is a notched flexural beam

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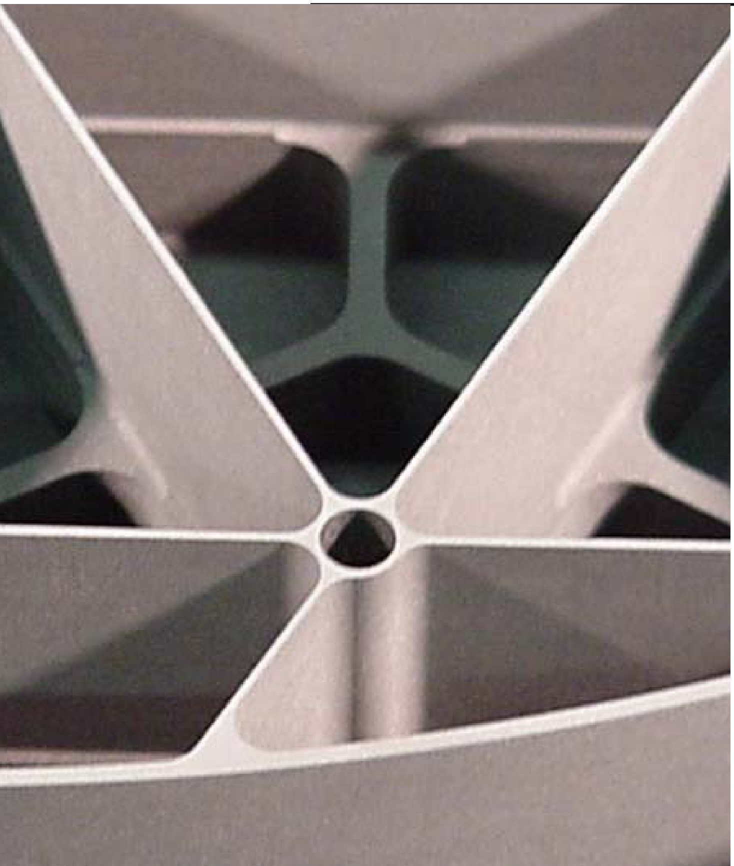

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Design Guide

Objectives

- POCO’s new design guide presents our general design guidelines
- Guidelines are compiled from POCO engineering ‘best-practices’
- The design guide provides our experienced understanding of the POCO’s SuperSiC® products.
- The design guide is intended to impart fundamental principles
- The guide is intended to assist designers and engineers in their component and assembly design with POCO materials.
- Additionally, machinists and those performing post-machining processes and handling will benefit from the information presented.

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